(MP3-4) The Hall Effect

Aim of experiment

Determination of the charge carrier number density of a conductor

Apparatus

Al-Metal Sample, DC Power Supply, Voltmeter, Ammeter, Electromagnet, Magnetic probe

Theory of experiment

In this experiment, the Hall Effect will be used to study some of the physics of charge transport in metals.
When an electrical current passes through a metal sample placed in a magnetic field, a potential proportional to the current and to the magnetic field is developed across the material in a direction perpendicular to both the current and to the magnetic field .This effect is known as the Hall effect, and is the basis of many practical applications and devices such as magnetic field measurements, and position and motion detectors. Also, Hall Effect measurements are a useful technique for characterizing the electrical transport properties of metals and semiconductors.

Consider a conducting slab as shown in figure 1 with length l in the x direction, width w in the y direction and thickness t in the z direction.

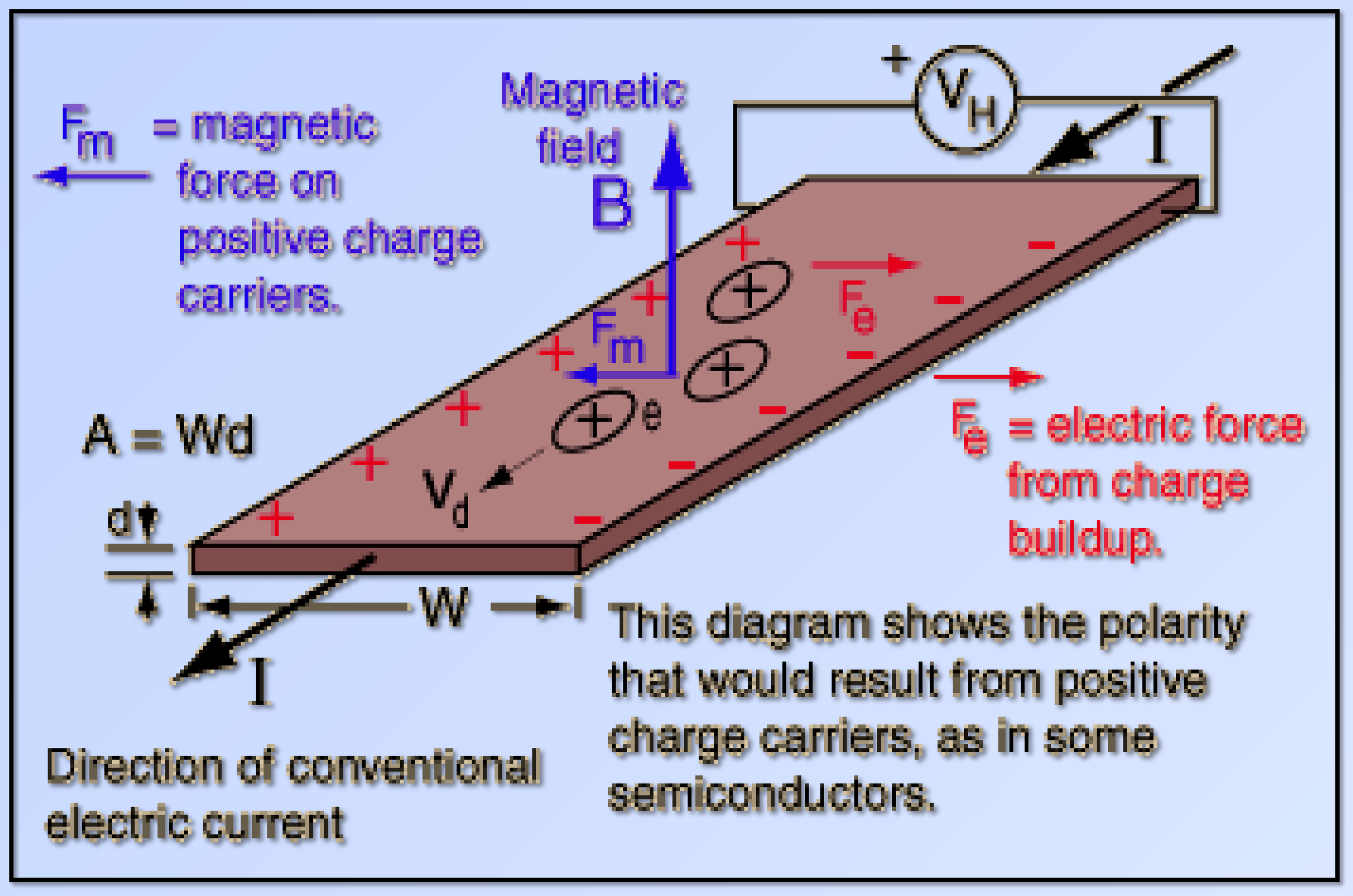

Figure 1. Geometry of fields and sample in Hall Effect experiment.

Assume the conductor to have charge carrier of charge q (can be either positive or negative or both, but we take it to be of just one sign here), charge carrier number density n (i.e., number of carriers per unit volume), and charge carrier drift velocity v_x when a current I_x flows in the positive x direction. The drift velocity is an average velocity of the charge carriers over the volume of the conductor; each charge carrier may move in a seemingly random way within the conductor, but under the influence of applied fields there will be a net transport of carriers along the length of the conductor. The current I_x is the current density J_x times the cross sectional area of the conductor wt. The current density J_x is the charge density nq times the drift velocity v_x. In other words

$$I_x = J_x\, wt = nqv_x\, wt \qquad (1)$$

The current I_x is caused by the application of an electric field along the length of the conductor. In the case where the current is directly proportional to the field, we say that the material obeys Ohm's law, which may be written;

$$J_x = \sigma E_x \qquad (2)$$

where σ is the conductivity of the material in the conductor.
Now assume that the conductor is placed in a magnetic field perpendicular to the plane of the slab. The charge carriers will experience a Lorentz force ***qv x B*** that will deflect them toward one side of the slab. The result of this deflection is to cause an accumulation of charges along one side of the slab which creates a transverse electric field E_y that counteracts the force of the magnetic field. (Recall that the force of an electric field on a charge q is qE.) When steady state is reached, there will be no net flow of charge in the y direction, since the electrical and magnetic forces on the charge carriers in that direction must be balanced. Assuming these conditions, it is easy to show that

$$E_y = v_x B_z \qquad (3)$$

where E_y is the electric field, called the Hall field, in the y direction and B_z the magnetic field in the z direction. In an experiment, we measure the potential difference across the sample, the Hall voltage, V_H which is related to the Hall field by

$$V_H = -E_y\, w \qquad (4)$$

Thus, from equations (1), (3) and (4) we obtain

$$V_H = -\left(\frac{1}{nq}\right)\frac{I_x B_z}{t} \qquad (5)$$

The term in parenthesis is known as the Hall coefficient:

$$R_H = \frac{1}{nq} \qquad (6)$$

It is positive if the charge carriers are positive, and negative if the charge carriers are negative. In practice, the polarity of V_H determines the sign of the charge carriers. Note that the SI units of the Hall coefficient are [m^3/C] or more commonly stated.

(MP3-4) The Hall Effect

If the magnetic field, B_z, supplied by an electromagnet, is constant and the Hall voltage, V_H, is measured as a function of the current I_x , a straight line relationship is obtained with a slope of

$$Slope = -\left(\frac{1}{nq}\right)\frac{B_z}{t} \qquad (7)$$

from which n and R_H of a conductor is obtained.

Procedure

1. Switch on the electromagnet and set B_z to a desired value by changing the current, IB
2. Set the current, I_x to the desired level, no more than 200 mA.
3. After the voltage reading settles, record the voltage.
4. Go back to step 1 with a new current setting.
5. Record your results in a table
6. Draw the relation between I_x and V_H
7. From the slope calculate n from equation (7)

Results

$I_B =$ A

I_x (A)	V_{H1}	V_{H2}	V_{H3}	$V_{Hav} + \Delta V_{Hav}$

$B_z =$ T, $e = 1.6x10^{-19}$ C

$t = 2.5 \text{ x}10^{-7}$ m

$$Slope = -\left(\frac{1}{nq}\right)\frac{B_z}{t}$$

, $n=$ $R=$